Medical Planning for Boldly Going Where No One Has Gone Before

National Aeronautics and Space Administration

Benjamin Easter, MD, MBA, FACEP

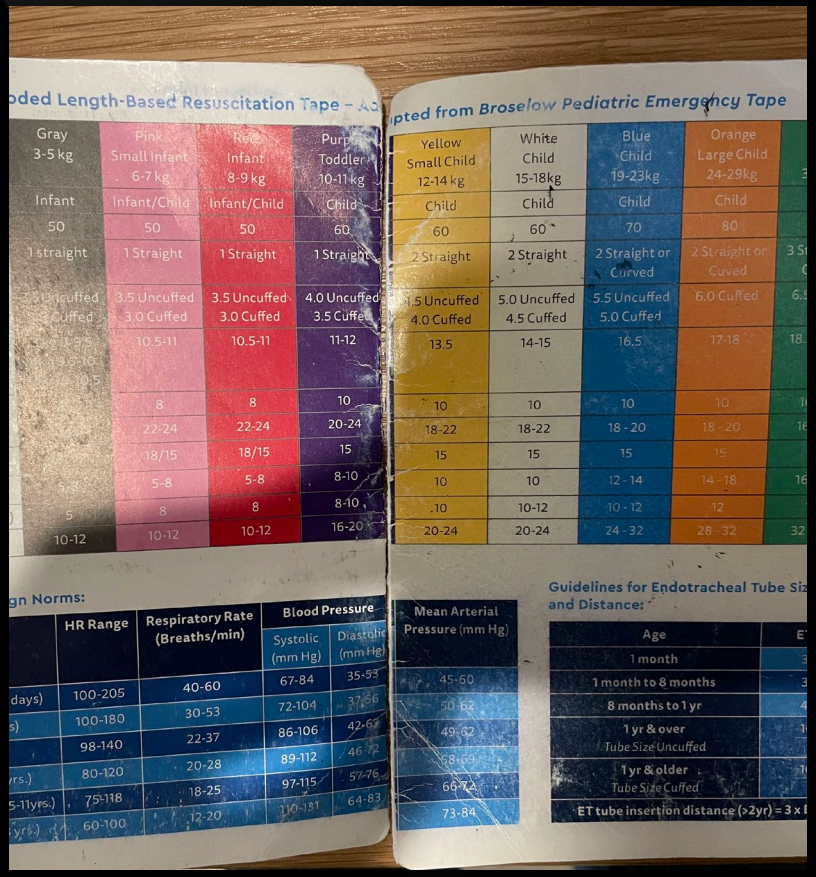
Deputy Element Scientist
Exploration Medical Capability (ExMC)
NASA Human Research Program

Assistant Professor of Emergency Medicine
University of Colorado School of Medicine

Florida Atlantic University Emergency Medicine Grand Rounds
15 February 2022

ARTEMIS

EXPLORATION MEDICAL CAPABILITY



What's the problem space?

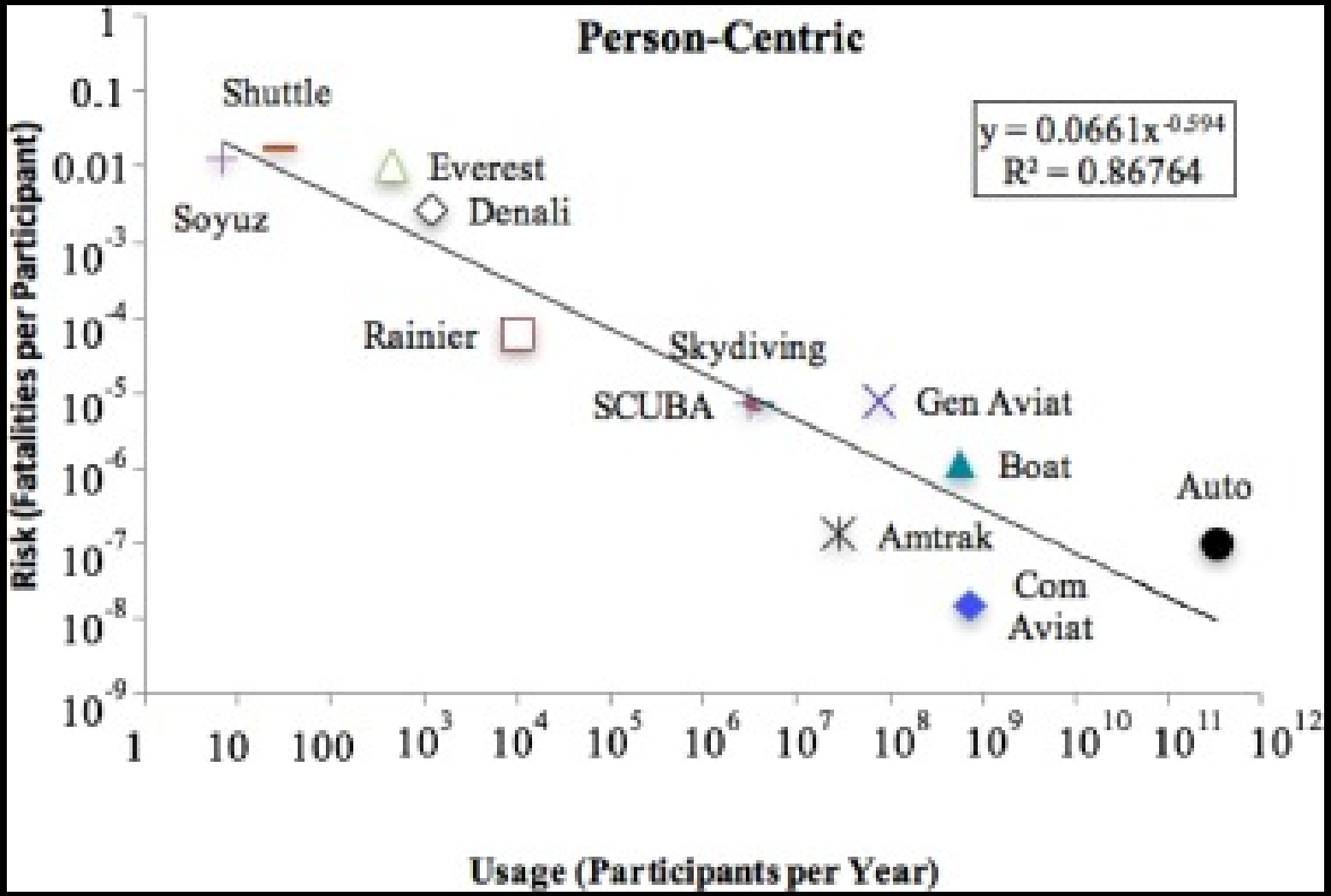
Now imagine if your ED was a Mars Medical System

- Pick everything you want for the next three years
- No more than 50 kg (notional)
- No resupply
- No real-time assistance (consults, UpToDate)
- No transfers

Agenda

- Designing Medical Systems for Human Spaceflight
- Martian Medical Analogue and Research Simulation
- How to get involved

Risk of Human Spaceflight



O'Campo RP, Klaus DM. Applying regression analysis to model the risk of space flight and terrestrial activities. Journal of Space Safety Engineering. Sep-Dec 2018;5(3-4): 135-139.

Medical events in and around spaceflight

Medical Condition	Events	Medical Condition	Events
Allergic reaction (mild to moderate)	11	Mouth ulcer	9
Ankle sprain/strain	11	Nasal congestion (space adaptation)	389
Back injury	31	Neck injury	9
Back pain (space adaptation)	382	Nose bleed (space adaptation)	6
Barotrauma (ear/sinus block)	31	Otitis externa	3
Choking/obstructed airway	3	Otitis media	3
Constipation (space adaptation)	113	Paresthesias	26
Diarrhea	33	Pharyngitis	11
Elbow sprain/strain	12	Respiratory infection	33
Eye abrasion (foreign body)	70	Shoulder sprain/strain	22
Eye chemical burn	6	Sinusitis	6
Eye infection	5	Skin abrasion	94
Finger dislocation	1	Skin infection	13
Fingernail delamination (EVA)	16	Skin laceration	1
Gastroenteritis	4	Skin rash	94
Headache (CO_2 induced)	20	Smoke inhalation	3
Headache (late)	49	Space motion sickness (space adaptation)	325
Headache (space adaptation)	233	Urinary incontinence (space adaptation)	5
Hemorrhoids	2	Urinary retention (space adaptation) – female	5
Herpes Zoster reactivation (shingles)	1	Urinary retention (space adaptation) – male	4
Indigestion	6	Urinary tract infection – female	5
Influenza	1	Urinary tract infection – male	4
Insomnia (space adaptation	299	Visual impairment/increased intracranial pressure (space adaptation)	15
Insomnia (late)	133	Wrist sprain/strain	5
Knee sprain/strain	7		

Antonsen E, Bayuse T, Blue RS, Daniels V, Hailey M, Hussey S, et al. The Risk of Adverse Health Outcomes and Decrements in Performance due to In-Flight Medical Conditions. National Aeronautics and Space Administration 2017; TR: NASA/TR-2017-0004604

Five Hazards of Human Spaceflight

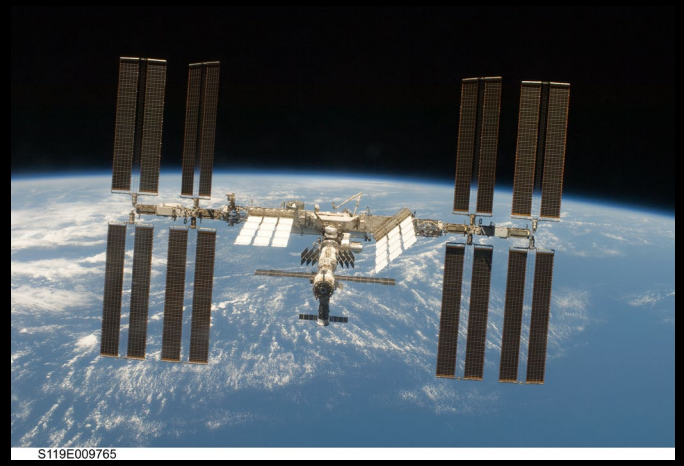
1. Distance from Earth
2. Hostile/Closed Environments
3. Isolation and Confinement

---

4. Radiation
5. Altered Gravity Fields

Trail Map

Low Earth Orbit



400 km

Moon

~400,000 km

Mars

~225,000,000 km (average)

1000x

560x

560,000x

Trail Map (by relative distances from Denver)

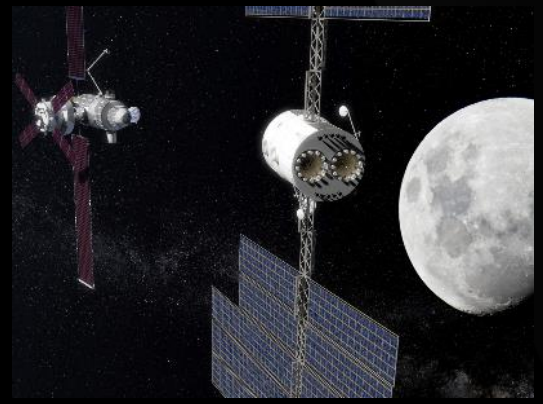
Backyard

Rocky Mountains

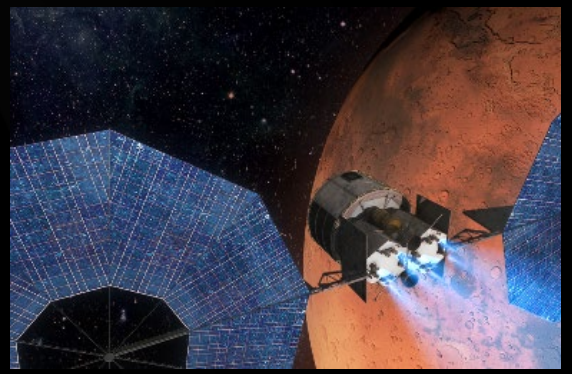
South Pole

Progressive Earth Independence

- Real Time Communications
- Real Time Mission Control
- Strong Consumables Resupply
- Evacuation Capability (1.5 – 36 hrs)



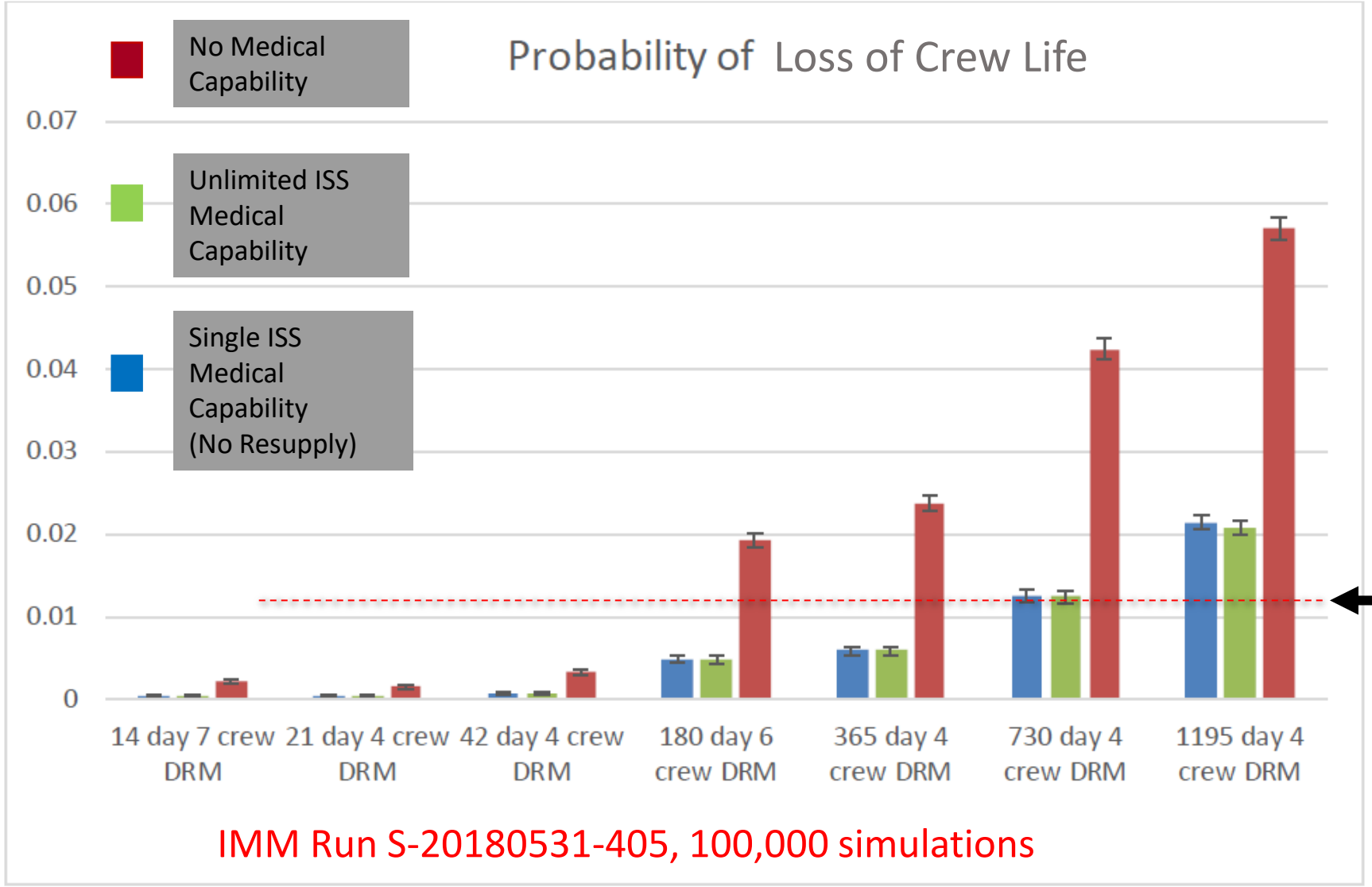
- Near Real Time Communications
- Near Real Time Mission Control
- **Limited** Consumables Resupply
- Evacuation Capability (72 – 144 hrs)



- **No** Real Time Communications
- Delayed Mission Support
- **No** Consumables Resupply
- **No** Evacuation Capability

Increasing exposure to Hazards

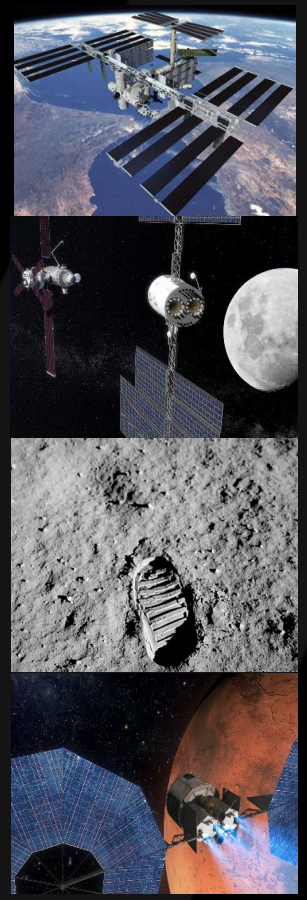
Risk Modeling of Loss of Crew from Medical Events



IMM Run S-20180531-405, 100,000 simulations

1/90 is where the Space Shuttle TOTAL risk for LOC fell at the end of the program (Bagian, JAMA Neurology, 2019)

Exploration Medical System Challenges



Human System Risk	On-Board Capabilities	On-Board Decision Making	Resources available for system
Lower	Less	Minimal	More
↓	↓	↓	↓
Higher	More	Substantial	Less

Influencers

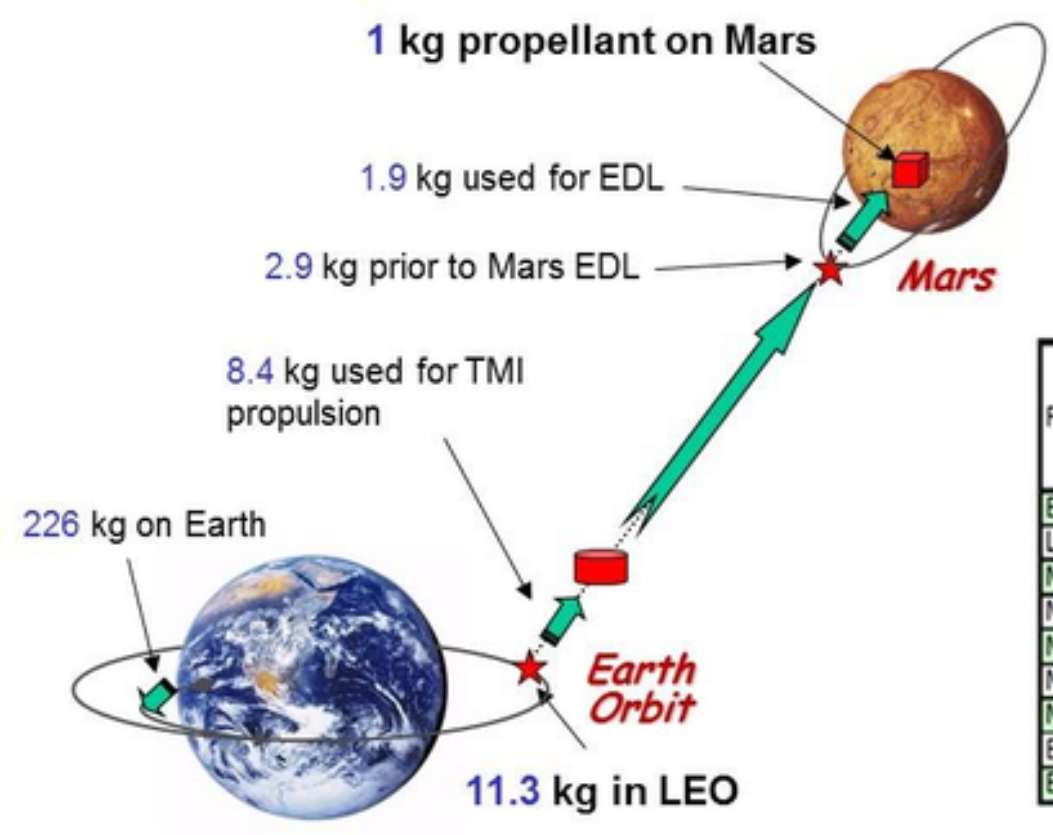
- Mission duration and objectives
- Distance from Earth
- Acceptable mission risk
- Time to definitive medical care
- Health and performance needs
- Level of training for on-board medical provider(s)
- Technology developments and medical advances

How do we solve this?

- Trade Space Analysis

The Backpack Problem

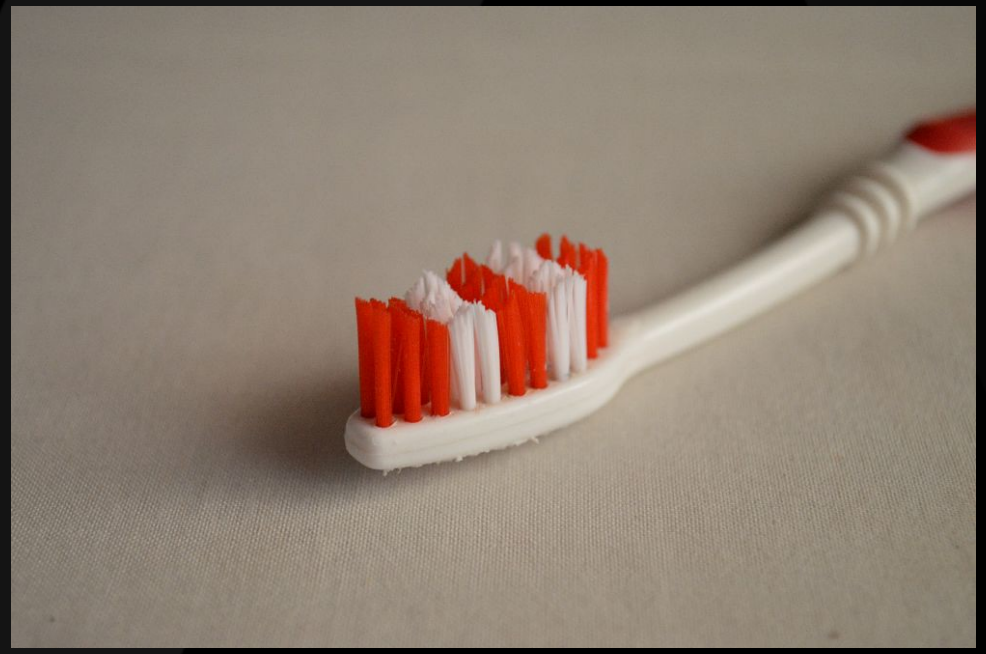
Mars Surface “Gear Ratios”



Estimates based on Aerocapture at Mars

From / To->	LEO	Mars Cruise	Mars Orbit	Mars Surface	Mars Ascent	Mars Orbit	Earth Cruise	Earth Orbit	Earth Surface
Earth	20	60	78	148	222	1489	4468	5809	7551
LEO		3	3.9	7.4	11	74	223	290	378
Mars Cruise			1.3	2.5	3.7	25	74	97	126
Mars Orbit				1.9	2.9	19	57	74	97
Mars Surface					1.5	10	30	39	51
Mars Ascent						6.7	20	26	34
Mars Orbit							3	3.9	5.1
Earth Cruise								1.3	1.7
Earth Orbit									1.3

https://arc.aiaa.org/doi/10.2514/6.2015-4458



We can’t fly everything that we want…

Mass

Power

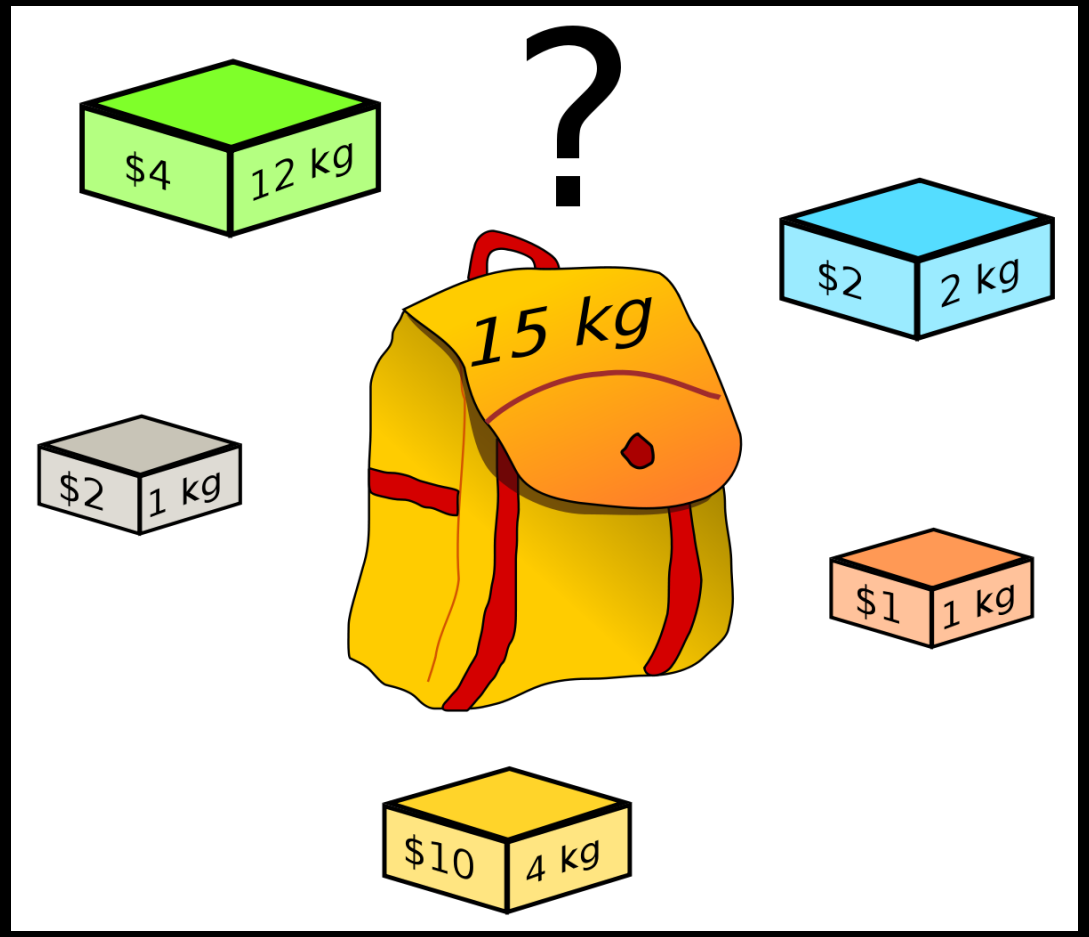
Volume

Data

Time

Skills/training

The Backpack Solution



- Optimization problem
- Maximize value subject to constraints
- Question: what combination of blocks yields the most money but does not exceed the weight limit?

Examples of backpack solutions

FIGURE 4.2. Mercury medical kit containing items such as saline solution, bandages, stimulants, and decongestants (Photo courtesy of NASA)

What is a “trade space”?

We cannot take everything we want or need for a medical system due to resource constraints.

We cannot research every conceivable technology due to time and funding constraints!

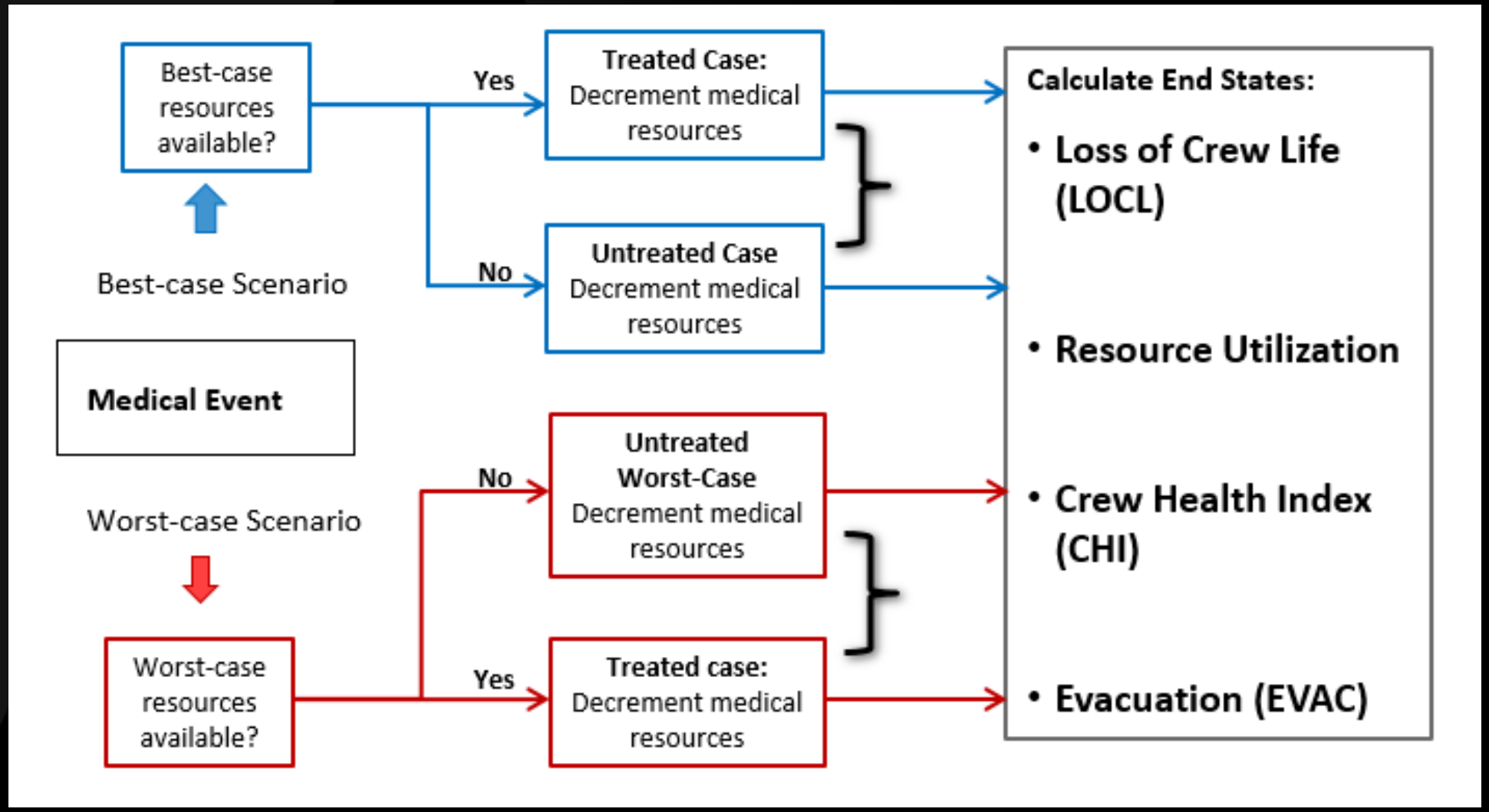
Optimization/Prioritization is necessary!

- Rigorous exercise to identify the most *acceptable* solution amongst a set of alternative solutions
- Enables a traceable and repeatable process
- Evaluations will assess metrics for:
  - Risk: Probabilities of loss of crew and loss of mission
  - Resource characterizations: mass, power, volume, etc.

What questions are in the medical trade space?

- What if spacewalks are added to the mission parameters?
- What if the mission were extended?
- What if mass allocation lowers by 25%?
- Which imaging technology is most useful? Ultrasound or X-ray?
- What is the medical risk of reducing crew's water rations from 3L to 2L daily?
- If I could reduce the mass or volume of a piece of medical equipment by 50%, would it make the cut to fly in space?

Probabilistic Risk Assessment



SKIN
- Burns secondary to Fire
- Skin Abrasion
- Skin Laceration

EYES
- Acute Glaucoma
- Eye Corneal Ulcer
- Eye Infection
- Retinal Detachment
- Eye Abrasion
- Eye Chemical Burn
- Eye Penetration

EARS, NOSE, THROAT
- Barotrauma (sinus block)
- Nasal Congestion (SA)
- Nosebleed (SA)
- Acute Sinusitis
- Hearing Loss
- Otitis Externa
- Otitis Media
- Pharyngitis

DENTAL
- Abscess
- Caries
- Exposed Pulp
- Tooth Loss
- Crown Loss
- Filling Loss

CARDIOVASCULAR
- Angina/Myocardial Infarction
- Atrial Fibrillation / Atrial Flutter
- Cardiogenic Shock secondary to Myocardial Infarction
- Hypertension
- Sudden Cardiac Arrest
- Traumatic Hypovolemic Shock

GASTROINTESTINAL
- Constipation (SA)
- Abdominal Injury
- Acute Cholecystitis
- Acute Diverticulitis
- Acute Pancreatitis
- Appendicitis
- Diarrhea
- Gastroenteritis
- Hemorrhoids
- Indigestion
- Small Bowel Obstruction

Pulmonary
- Choking/Obstructed Airway
- Respiratory Infection
- Toxic Exposure: Ammonia
- Smoke Inhalation
- Chest Injury

*SA – Space Adaptation

NEUROLOGIC
- Space Motion Sickness (SA)
- Head Injury
- Seizures
- Headache
- Stroke
- Paresthesia
- Headache (SA)
- Neurogenic Shock
- VIIP (SA)

MUSKULOSKELETAL
- Back Pain (SA)
- Abdominal Wall Hernia
- Acute Arthritis
- Back Injury
- Ankle Sprain/Strain
- Elbow Dislocation
- Elbow Sprain/Strain
- Finger Dislocation
- Fingernail Delamination (EVA)
- Hip Sprain/Strain
- Hip/Proximal Femur Fracture
- Knee Sprain/Strain
- Lower Extremity Stress fracture
- Lumbar Spine Fracture
- Shoulder Dislocation
- Shoulder Sprain/Strain
- Acute Compartment Syndrome
- Neck Injury
- Wrist Sprain/Strain
- Wrist Fracture

PSYCHIATRIC
- Insomnia (Space Adaptation)
- Late Insomnia
- Anxiety
- Behavioral Emergency
- Depression

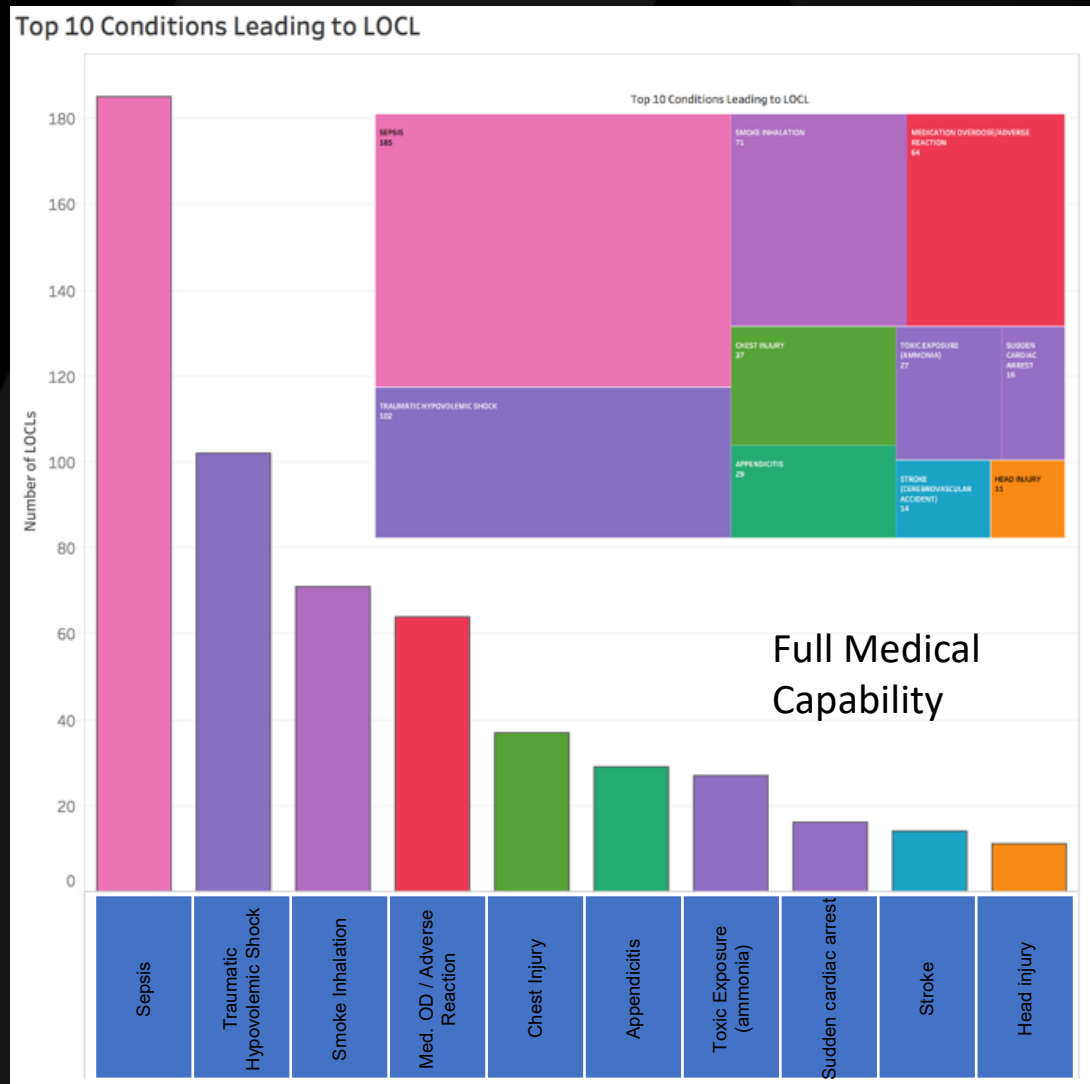
GENITOURINARY
- Abnormal Uterine Bleeding
- Acute Prostatitis
- Nephrolithiasis
- Urinary Incontinence (SA)
- Urinary Retention (SA)
- Vaginal Yeast Infection

INFECTION
- Herpes Zoster (shingles)
- Influenza
- Mouth Ulcer
- Sepsis
- Skin Infection
- Urinary Tract Infection

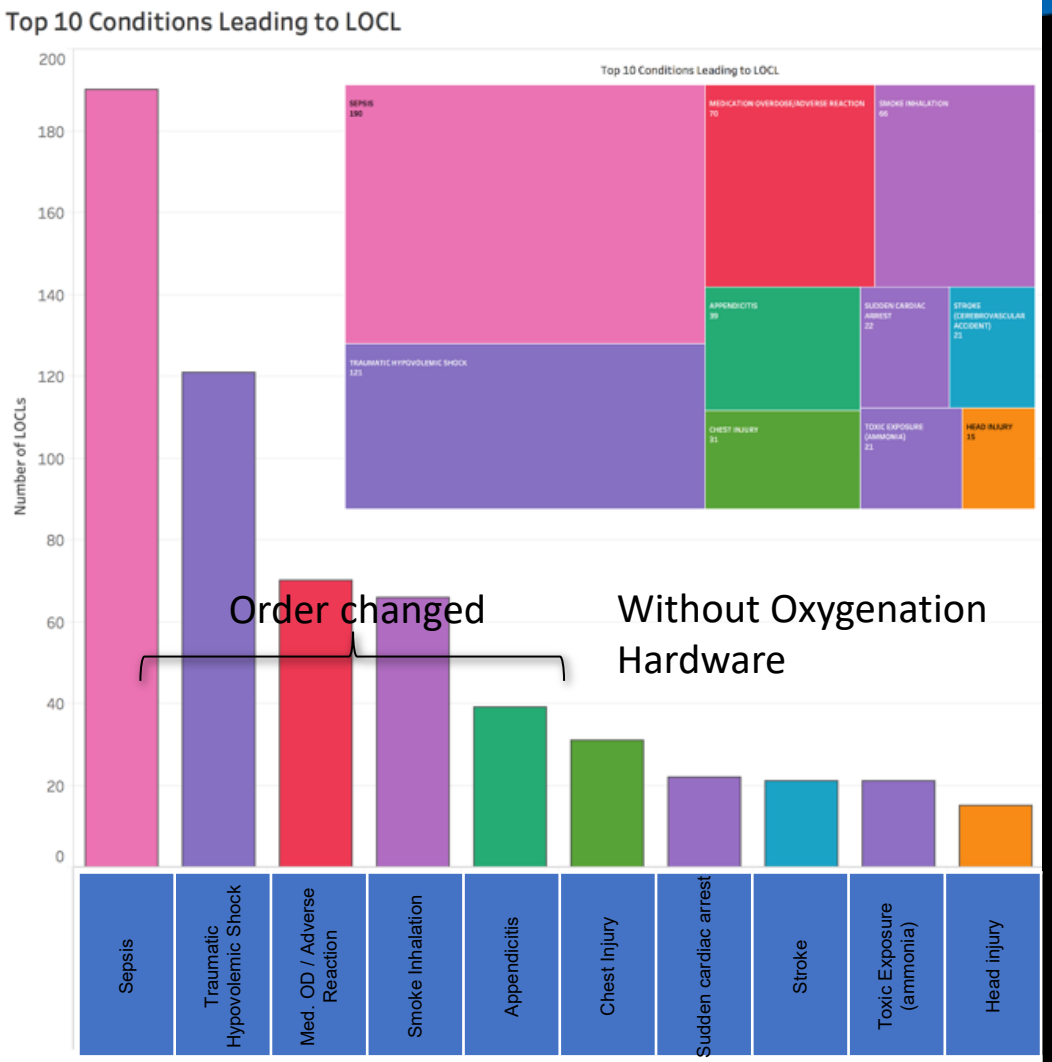
IMMUNE
- Allergic Reaction
- Anaphylaxis
- Skin Rash
- Medication Reaction

ENVIRONMENT
- Acute Radiation Syndrome
- Altitude Sickness
- Decompression Sickness (EVA)
- Headache (CO_2)

Examples of Output Visualizations for Clinicians

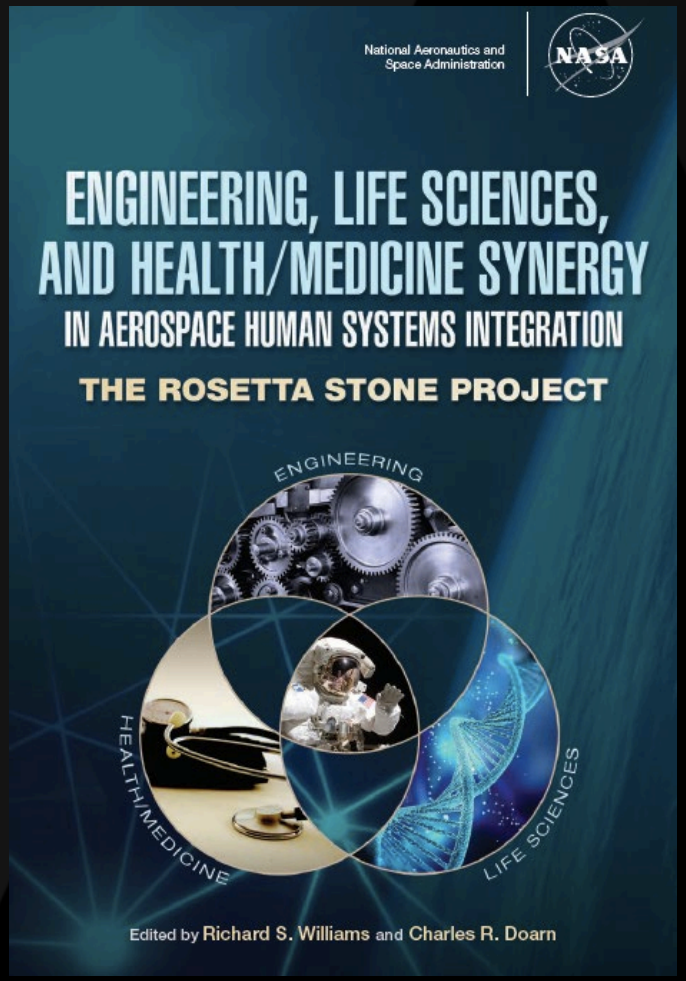


Run 1, med system



Run 2, resources removed

How much risk is from medical problems?



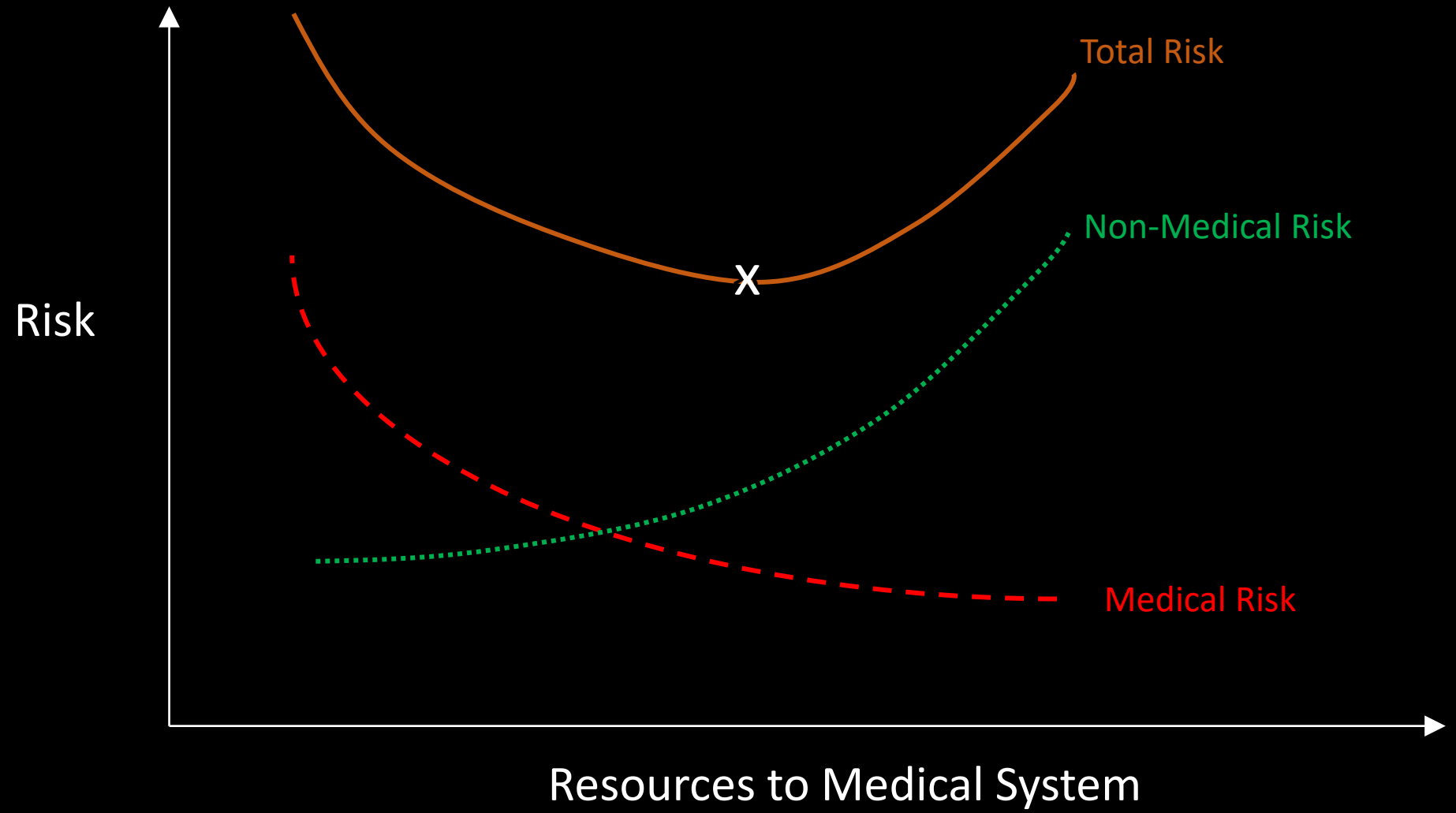
"…[The] assumption has been that risk of vehicle system malfunction far outweighs the risk of human system failure…NASA buys down the risk of failure of the human system through rigorous selection of individuals designed to minimize medical issues and optimize available capability in flight."

NASA SP-2017-0633

How do you visualize the medical trade space?

System Characteristic	System 1- Run 1	System 2-Run 2
Mass (kg)	115.2	106.6
Prob of Loss of Crew	0.0057	0.0061
Prob of EVAC	0.0999	0.101
Crew Health Index	0.929	0.928
Requirements not met	0	4
Conditions not addressed	0	32

Minimizing Medical Risk is NOT the Goal



Notional

A Medical System Alone is Insufficient

Habitat System

Crew Health and Performance

Natural and Induced Environments Protection

Medical

Mission Task Performance

Health and Wellness

Crew as Physician

Crew as Explorer or Patient

Structures

Command & Data Handling

Guidance, Navigation and Control

Comm & Tracking

Power

etc.

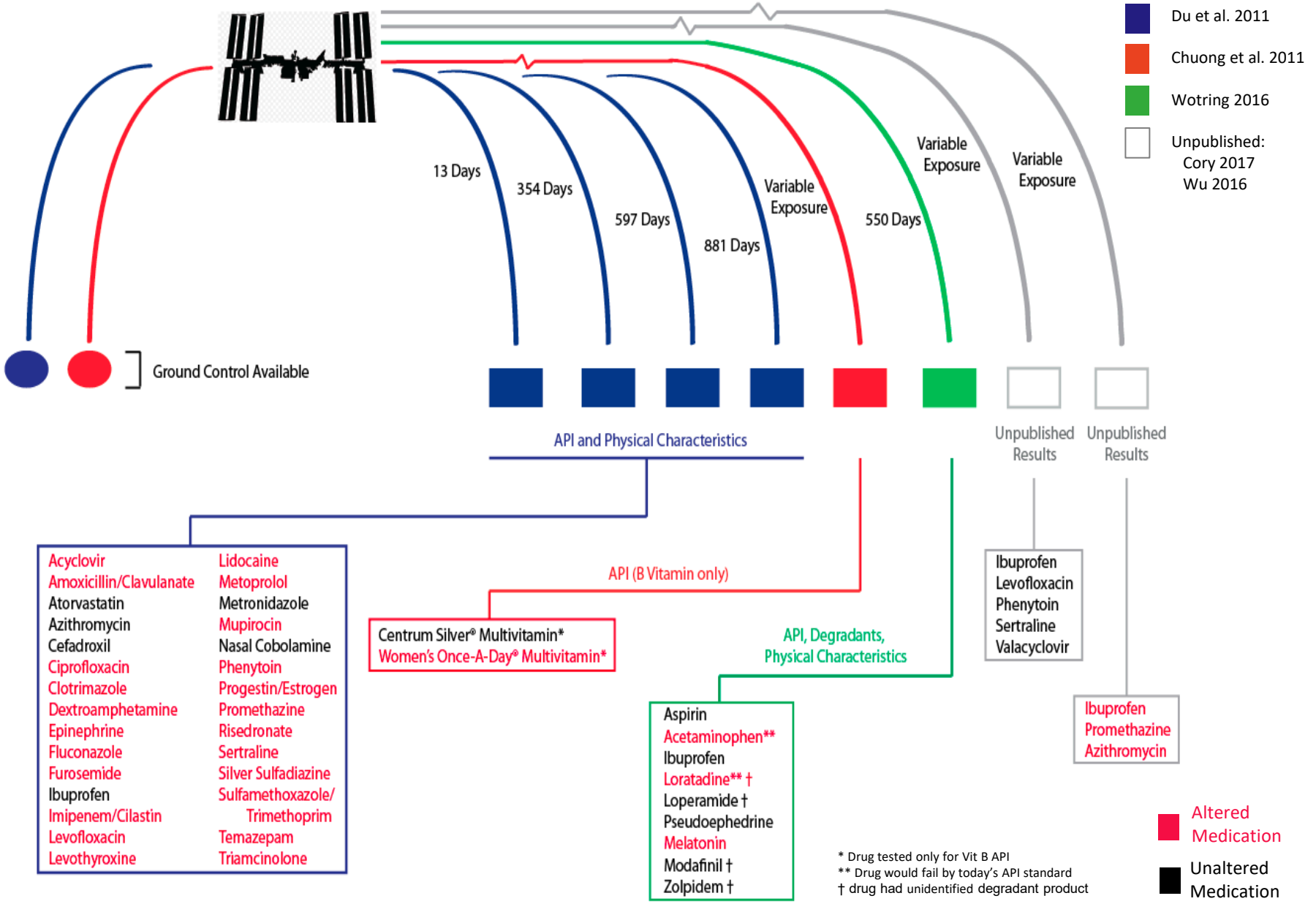
Ground System

MedOps

National Aeronautics and Space Administration

Quick Hits on Other ExMC Focus Areas

Blue et al., 2019



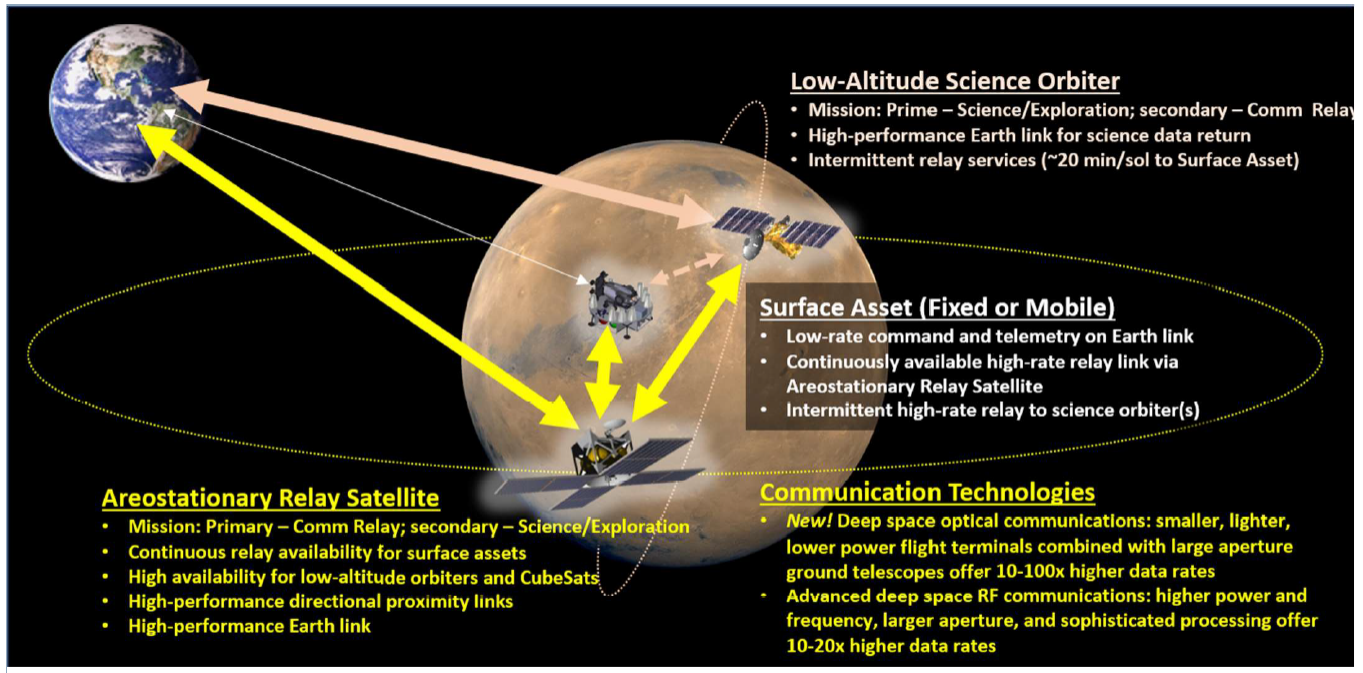
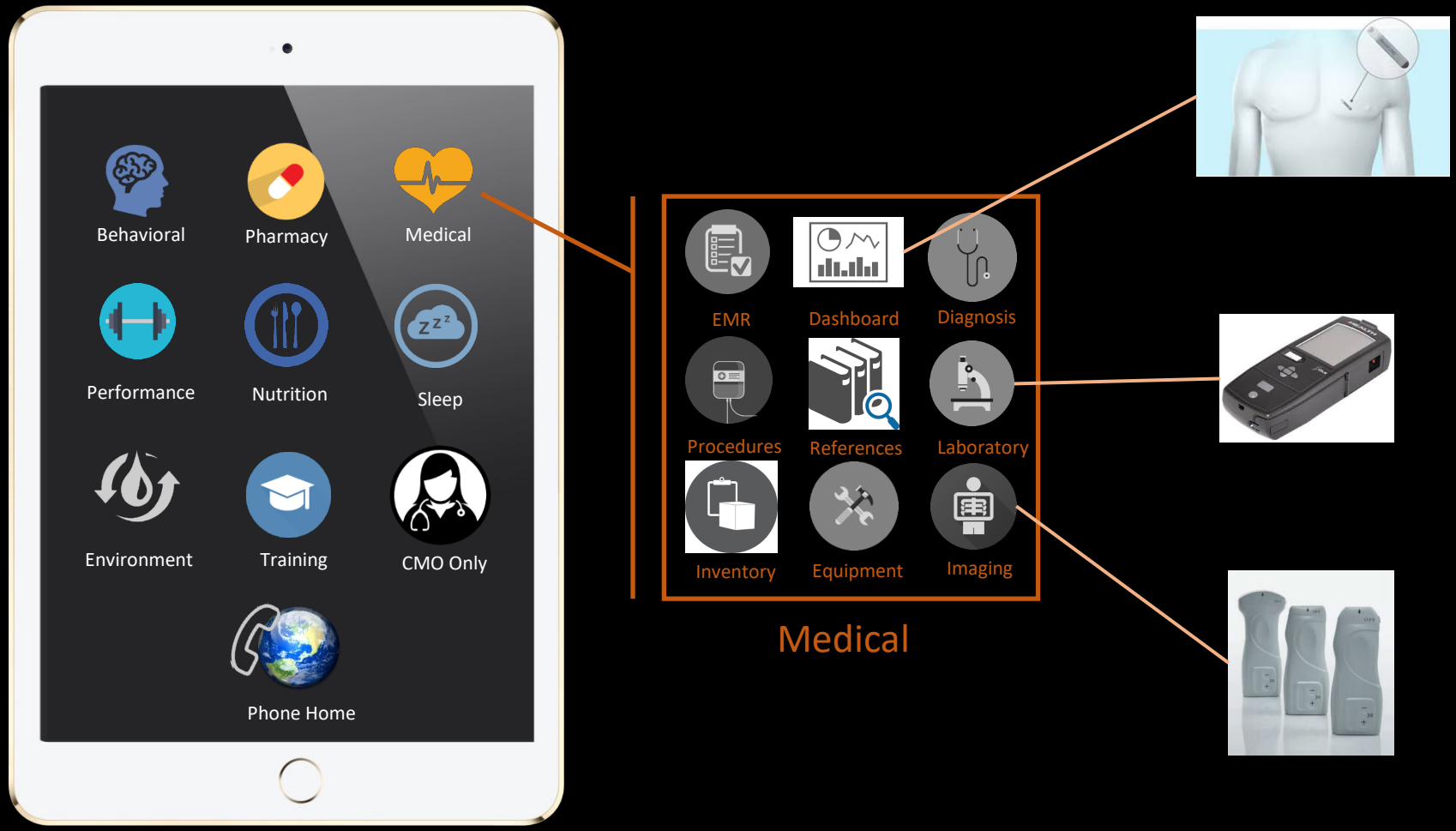


Figure 1. Advanced RF and optical communications technologies combined with using the areostationary orbit offer 100-1000x greater data return from Mars and nearly continuous availability.

Table 1. High-Performance Mars-Earth Trunk Line Capability

	Frequency Band	Maturity	S/C Aperture	S/C Txmt Power	Ground Receiver	Data Rate (@ 2 AU)
Current State-of-the-Art (MRO)	X-band	Operational	3 m	100 W	34 m DSN BWG antenna	**1 Mb/s**
Next-Generation Trunk Line Options	Ka-band	TRL 6	3 m	200 W	34 m DSN BWG antenna	**5 Mb/s**
		TRL 3-4	5 m	1 kW	34 m DSN BWG antenna	**70 Mb/s**
	Optical (1550 nm)	TRL 6 (DSOC; to fly on 2023 Psyche Discovery Mission	22 cm	4 W	5 m ground telescope	**1 Mb/s**
		TRL 3	50 cm	50 W	12 m ground telescope	**100 Mb/s**

We’re not bringing an Intensive Care Unit but…



Notional

Medical Technology Demonstrations

Autonomous Medical Officer Support (AMOS)

- AMOS used to perform ultrasound of the bladder and kidneys in **autonomous fashion with no preflight training and no support from the ground**
- **1st spaceflight performance** of fully autonomous, untrained imaging
- Awarded the International Space Station Research and Development **2020 Compelling Results Award- Human Health**

Hemocue ®

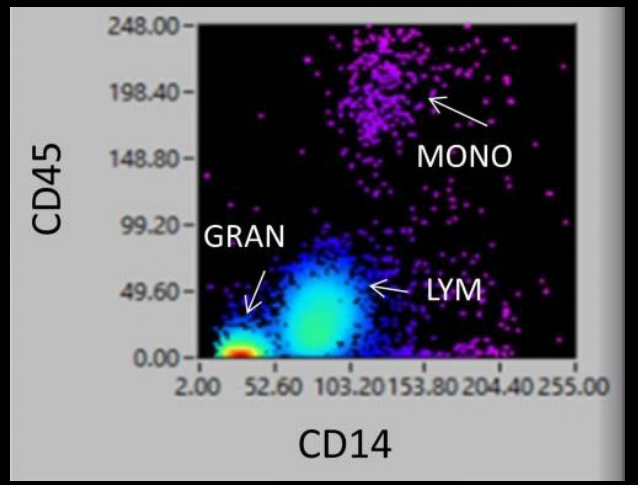
- Device for **point-of-care** analysis of white blood cell count and differential
- Validated performance in flight using control solutions and a fingerstick blood sample
- **1st real-time hematology performed in space**

Exploration Lab Analysis

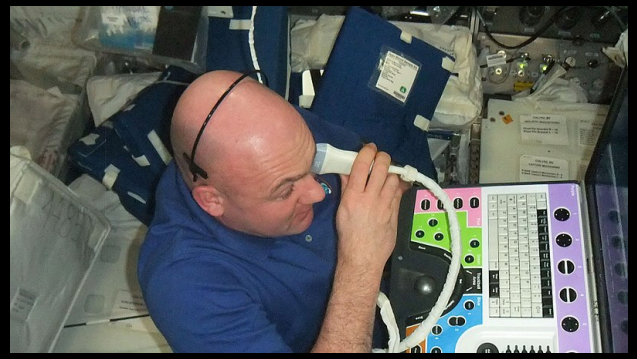
- Currently, no ability to perform real-time lab analysis in flight

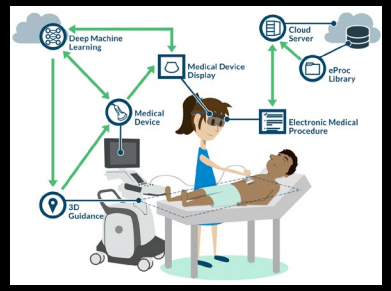
- Required Assays
  - Metabolic Panel (components)
  - Blood Counts (components)
  - Urine
- Desired Assays
  - Cardiac, Blood Gases, Coags, ID

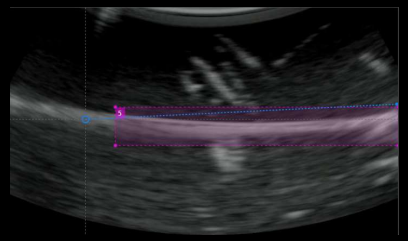
- Challenges
  - Reduce/eliminate waste
  - Fluidics in microgravity
  - Maintain industry standards



Imaging in the Exploration Environment







- Why imaging?
  - Of the 100 conditions that we scope medical system for:
    - 44 amenable to US
    - 27 amenable to XR
  - Possibly therapeutic (renal stone propulsion trial)
- Current Capability
- Challenges
  - Training
  - Obtaining high quality images (COMfORT, AR/VR, automated)
  - Image interpretation (store and forward, AI/ML)

Questions?

benjamin.easter@nasa.gov
@beasterMD

Trademark Statement

Trade names and trademarks are used in this report for identification only. Their usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.